Improved Techniques for Targeting Additional Observations to Improve Forecast Skill

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LONG-TERM GOAL

This project aims to improve weather forecasts using adaptive observation techniques based on targeted singular vector analysis with a particular focus on severe weather events in the tropics and extratropics in the range 0–5 days.

OBJECTIVES

The following objectives are and will be pursued. Aspects in the singular vector computation which are potentially important for observation targeting are investigated: the role of the initial time metric, in particular the inclusion of information about the analysis error covariances in the metric; the spatial resolution of the singular vectors; and the inclusion of moist processes in the formulation of the tangent-linear and adjoint models. Furthermore, the problem of the appropriate size of the target region and the problem of the appropriate sampling are addressed. In addition, it is planned to study the impact of targeted observations on probabilistic forecasts. Finally, it is hoped to be able to use the improved targeting techniques in real-time targeted observation experiments.

APPROACH

In the operational Ensemble Prediction System at ECMWF singular vectors (SVs) are computed using a total energy norm at initial and final time. Of the "simple" norms the total energy norm best approximates the analysis error covariance norm. Alternatively, so called Hessian singular vectors (HSVs) can be computed using an initial time norm based on an estimate of the analysis error covariances that is consistent with the variational assimilation scheme. This estimate is provided by the Hessian of the cost function of the variational assimilation scheme. A generalized Davidson algorithm is used to solve the generalized eigenproblem. The cost function comprises a part that measures the deviation from the first guess (background) and a part that quantifies the deviation from the observed values. The role of observations in the Hessian metric has been determined by desactivating

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14. ABSTRACT
This project aims to improve weather forecasts using adaptive observation techniques based on targeted singular vector analysis with a particular focus on severe weather events in the tropics and extratropics in the range 0???5 days.

15. SUBJECT TERMS

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some or all observations in the observational part of the cost function.

Tim Palmer is managing the overall development of the ECMWF ensemble prediction system. Martin Leutbecher is evaluating the impact of targeted observations and is investigating the role of the initial time metric for the singular vector structure. Jan Barkmeijer is working on singular vectors with higher spatial resolution and on the impact of moist processes on their structures. At Meteo-France, Thierry Bergot and Alex Doerenbecher have developed a different approach of taking the data assimilation scheme into account in an adaptive observation strategy. Gwenaëlle Hello studies whether the background error covariance estimate used in the assimilation scheme can be adjusted locally to improve the impact of the existing data. These ideas are generally tested on the set of FASTEX cases. In addition, the storms at the end of December 1999 are considered.

WORK COMPLETED

The impact of targeted observations has been evaluated for an additional case of a severe extratropical storm (Danish storm, 3 December 1999). For the first French storm (26 December 1999) further impact experiments have been performed with different amounts of soundings and varying spatial coverage. In addition, experiments have been performed in which the synthetic observations are perturbed with noise to represent the effect of observational error. The results of the experiments for the two extratropical storms are described in a recently submitted paper (Leutbecher et al. 2001).

The dependency of the structure of Hessian singular vectors on the choice of observations in the initial time singular vector norm was determined (see below).

RESULTS

The results in this section focus on the role of observations in the Hessian metric for the structure of the SVs. As example we show SVs computed for a 48-hour optimization period starting on 24 December 1999, 12 UT. The SVs are optimized for total energy in the region 20W–20E, 35–60N using the dry versions of the tangent-linear and adjoint models. These SVs are relevant for the case of the first French storm. They define the region in which additional observations would have been likely to improve the 2-day forecast of the storm. Their structure matters *inter alia* for choosing appropriate observing instruments and sampling patterns.

The Hessian metric depends on the spatial distribution of observations and their error characteristics as well as the formulation of the background error covariances. The latter are thought to be responsible that HSVs having larger scale structures than total energy SVs (Barkmeijer et al. 1999). The background error covariances are specified with broad horizontal and vertical correlations which penalize the occurrence of baroclinic structures. On the other hand, the HSVs computed for the first French storm case exhibit a tilt in the vertical similar to that of the total energy SVs (Fig. 1a,f). When the singular vectors are computed with no observation term in the cost function, the tilt disappears (Fig. 1b). In this case the Hessian of the cost function yields the inverse of the background error covariance matrix.

One might suspect that the use of the 4dvar cost function in the Hessian metric is crucial for obtaining the tilted singular vectors as the 4dvar assimilation scheme is able to produce baroclinically tilted analysis increments as opposed to 3dvar. However, the tilt changes little if the Hessian metric is computed with the 3dvar cost function (Fig. 1c). Another important recent change to the ECMWF forecasting system is the formulation of the background error covariances. The old formulation of the covariances is based on differences of lagged forecasts (NMC method). In the current formulation the covariances are determined from an ensemble of analyses. The ensemble is obtained from perturbing the observed values. The new formulation is known for tighter vertical correlations of the balanced variables. However, switching back to the old formulation of the background error covariances shows little impact on the tilt (Fig. 1d)

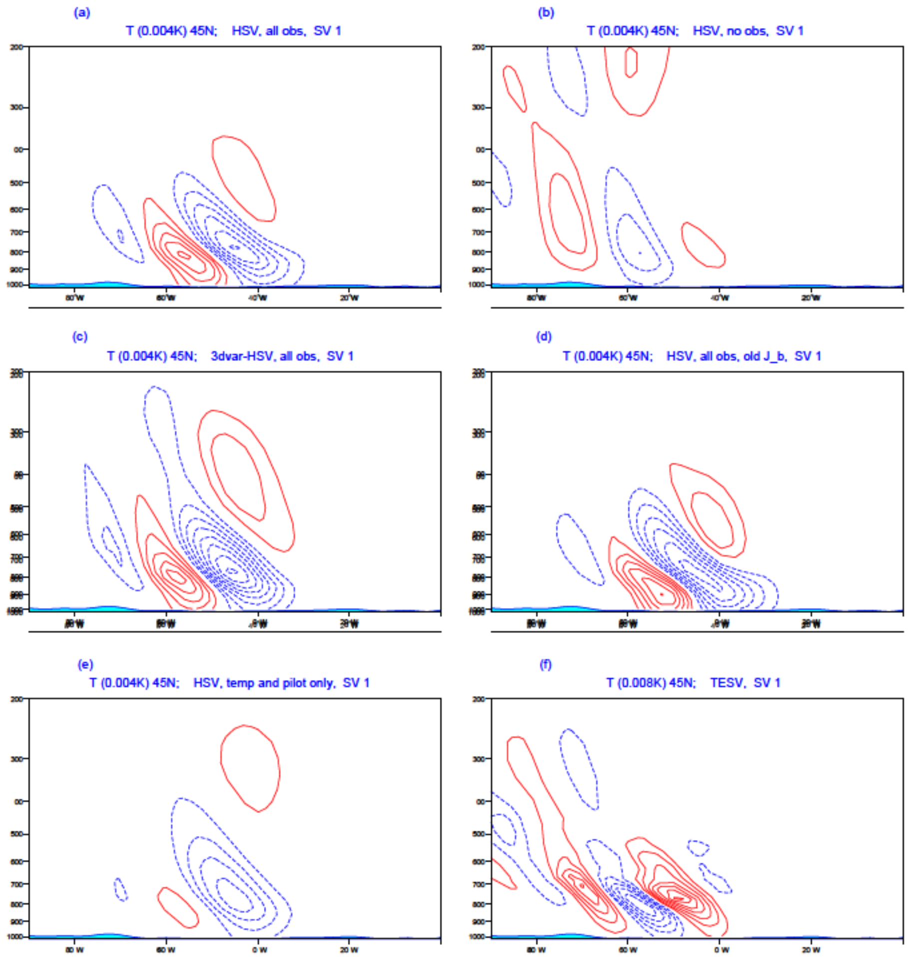

Fig. 1: Temperature in vertical section at 45° N through the leading singular vector computed with different norms at initial time: (a) Hessian all obs metric, (b) Hessian no obs metric, (c) 3dvar-Hessian all obs metric, (d) Hessian all obs metric using the old J_b formulation, (e) Hessian metric using TEMP and PILOT observations only, (f) total energy metric.

Next, we determined which types of observations are crucial to obtain tilted structures by computing singular vectors using different subsets of the routine observations in the Hessian metric: (i) conventional surface observations (SYNOP, DRIBU), (ii) conventional soundings (TEMP, PILOT), (iii) aircraft reports (AIREP), (iv) cloud motion winds from satellite imagery (SATOB), (v) satellite radiance data (SATEM). The conventional soundings were the only subset that when used in the metric resulted in structures with a similar tilt as the SVs using all routine observations in the Hessian metric (Fig. 1e). The addition of surface observations as well as the addition of aircraft reports to the conventional soundings in the metric reduces the vertical scale of the resulting singular vectors further.

The use of all satellite data (iv and v) in the metric still results in HSVs that are quite similar in terms of the vertical tilt to the HSVs using no observations in the metric.

Further insight into the differences between the singular vectors computed with and without observations in the Hessian metric is gained by splitting the "singular value" of a structure $\mathbf{x}$ into two factors:

$$\frac{\|\mathbf{Px}(t_1)\|_{\mathrm{te}}}{\|\mathbf{x}(t_0)\|_{\mathrm{c}}} = \frac{\|\mathbf{x}(t_0)\|_{\mathrm{te}}}{\|\mathbf{x}(t_0)\|_{\mathrm{c}}} \frac{\|\mathbf{Px}(t_1)\|_{\mathrm{te}}}{\|\mathbf{x}(t_0)\|_{\mathrm{te}}} \tag{1}$$

Here, t_0 and t_1 are the initial and final time of the optimization period and $\| \ \|_{\mathrm{te}}$ denotes the total energy metric and $\| \ \|_c$ the covariance metric induced by the Hessian. We will refer to the Hessian metric with all routine observations as the analysis error covariance metric and to the Hessian metric without any observations as the background error covariance metric — keeping in mind that the Hessian only provides an *estimate* of the respective covariance matrices. We will refer to the SVs computed with the analysis (background) error covariance metric as ASVs (BSVs). The inverse of the first factor in (1) measures the likelihood of structures on the unit total energy sphere. The probability is to be understood as that associated with a normal distribution having the same covariance as that used to define $\| \ \|_{\mathrm{c}}$. The larger the value of $\|\mathbf{x}(t_0)\|_{\mathrm{c}}/\|\mathbf{x}(t_0)\|_{\mathrm{te}}$ the less likely is a structure. The second factor measures the total energy growth including the projection to the target region given by the operator $\mathbf{P}$.

By definition the total energy SVs maximize the second factor in (1). For a given singular vector index the Hessian SVs grows about half as much as the corresponding total energy SV. The total energy SVs grow faster than the Hessian SVs but they are very unlikely structures in terms of the statistics implied by the analysis error covariance norm and the background error covariance norm. For unit total energy the covariance norm ranges between 2 and 6 for the first 25 total energy SVs. The value of the covariance norm of the ASVs is about an order of magnitude smaller (Fig. 2a). Thus, their somewhat smaller growth is by far outweighed by their larger likelihood.

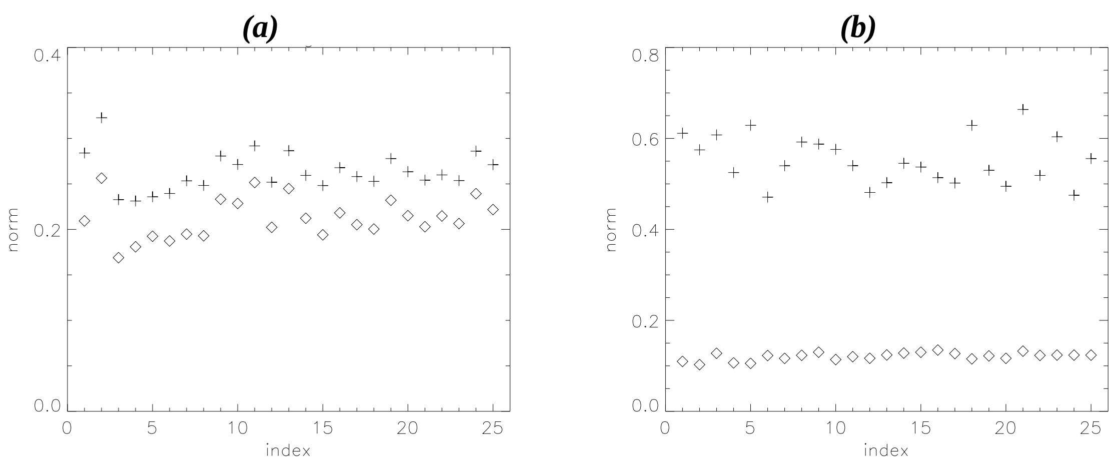

Fig. 2: Analysis error covariance norm (crosses) and background error covariance norm (diamonds) of singular vectors having unit total energy norm. (a) Singular vectors computed with Hessian all obs metric, (b) singular vectors computed with Hessian no obs metric.

For the ASVs, the ratio between the analysis error covariance norm and the background error covariance norm is about 1.3. Thus the likelihood of a structure is similar for the analysis error statistics and the background error statistics. However, the ratio between the two norms is about 5 for the

BSVs (Fig. 2b). Thus the occurence of a BSV as perturbation is considerably more unprobable in the analysis error statistic than in the background error statistic. This implies that the BSVs are structures that are much better observed by the routine observing network than the structures given by the ASVs. The difference of the total energy growth between ASVs and BSVs is minor as compared to the differences of the covariance norms. For most SV-indices the ASV grows somewhat faster than the BSV.

IMPACT/APPLICATIONS

This study may help transform the method by which atmospheric observations are taken. At the moment, the project rather confirms the overall singular vector approach of targeting as implemented during FASTEX by several centers including the NRL, although the choice of an analysis error covariance-based norm appears important.

RELATED PROJECTS

The techniques described in this report could be utilised in the proposed THORPEX experiment.

SUMMARY

Whether a certain pertubation to an analysis is a likely perturbation can be quantified with the Hessian metric. It is based on an estimate of the analysis error covariance that is consistent with the variational assimilation scheme. The importance of the inclusion of the observation term in the Hessian metric has been clearly demonstrated. Without observations in the metric singular vectors with broad horizontal and vertical structures are obtained. The inclusion of observations in the metric severely penalizes these broad scale structures.

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